Crop Mergers: Management of Soil Contamination and Leaf Loss in Alfalfa

M. F. Digman, K. J. Shinners, M. E. Boettcher

Abstract. *Maximizing the capacity and subsequent efficiency of the forage harvester necessitates consolidation (raking or merging) of alfalfa cuttings. Although rotary rakes are in wide use, the use of continuous pickup belt mergers is trending upward in the Midwestern United States. Previous work on crop consolidation is limited to rakes and inverters available during the time period and, therefore, does not consider modern merger designs or harvesting practices. In this study, theoretical field capacity, headland time, leaf loss, and the efficacy of a tine-pickup belt merger to incorporate ash (soil) into windrows were investigated by on-farm observation and through a controlled experiment. The experimental portion employed a factorial design to study the influence of two moisture levels (65% and 40% w.b.) and three cutting heights (5.1, 7.6, and 10.2 cm) on the ash incorporation and leaf loss of a belt merger. In the controlled experiment, windrow ash content increased statistically but not practically with lower cutting heights and lower swath moisture. Managing windrow ash with cutting height resulted in an average yield loss of 0.16 Mg ha^{-1} cm^{-1}. Leaf loss was observed to increase with decreased swath moisture from 1.1% to 2.2% of total biomass. The on-farm survey included four operations comprised of two owner-operators and two custom-operators, as well as five separate machine-tractor-operator combinations. Here, a variety of merging practices were revealed, yielding a range of theoretical field capacities from 13.2 to 16.9 ha h^{-1}. Each operation managed tractor engine speed below rated PTO speed resulting in fuel rates between 1.7 to 1.9 L ha^{-1}, which were less than predicted by ASABE models. As with the experimental work, the use of a belt-type merger was not attributed to significant amounts of windrow contamination.*

Keywords. *Alfalfa, Ash, Leaf loss, Merger, Belt merger, Continuous-pickup belt merger, Crop consolidation.*

Forage is the main ingredient in the diet of the U.S. dairy industry. Over 37.4 million acres of dry hay and haylage and 5.5 million acres of corn silage meet the needs of 9.1 million dairy cows. The dairy industry is the second largest livestock sector behind meat production, and it has a farm value equal to corn (USDA-ERS, 2011). The total dairy-industrial output the United States is $48 billion, producing more than 300,000 jobs (USDA-NASS, 2008). The raw material and the subsequent global competitiveness of this economic engine are dependent on high-quality forage. Most of the forages fed to dairy cattle are harvested and stored wet. This provides a uniformly high-quality feedstuff throughout the winter or non-production months. To facilitate the preservation of wet forage, the forage needs to be size-reduced and packed so as to exclude oxygen. The absence of oxygen promotes the growth of naturally occurring lactic acid-producing bacteria and other related genera. The conversion of the soluble sugars present in the forage into a mixture of organic acids and alcohols lowers the pH until bacterial growth ceases, thereby preserving the remaining crop. A forage harvester performs the size-reduction task essential to densification and the subsequent anaerobic preservation.

Modern forage harvesters have increased in capacity to meet the need for a timely harvest of today's high-yielding corn silage hybrids. Therefore, extra capacity exists when harvesting alfalfa, the per-cutting yield of which is considerably less than that of corn silage. Because modern forage harvesters can cost more than $450,000 and corn silage harvest occurs only in autumn, there is an economic benefit to diluting the capital investment by using the same machine to harvest both crops. To better match the harvesting capacity of the forage harvester, the lower-yielding alfalfa cuttings must be consolidated (merged or raked) before harvest with the forage harvester. This is especially true for the later cuttings. Maximizing the capacity of the forage harvester in lower-yielding crops can reduce the amount of time and energy needed to harvest the crop. This is partly because 25% of the harvester's energy is used for processes other than chopping and conveying crop (Srivastava et al., 2006). Thus, if a forage harvester can process more crop for a given speed, it can do so with less energy, thereby reducing the environmental impact of the field process (Wild et al., 2009).

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The authors are **Matthew Francis Digman, ASABE Member,** Research Agricultural Engineer, U.S. Dairy Forage Research Center, Cell Wall Biology and Utilization Research Unit, Madison, Wisconsin; **Kevin J. Shinners, ASABE Member,** Professor, Biological Systems Engineering Department, University of Wisconsin – Madison, Madison, Wisconsin; and **Michael E. Boettcher,** Mechanical Engineer, U.S. Dairy Forage Research Center, Cell Wall Biology and Utilization Research Unit, Madison, Wisconsin. **Corresponding author:** Matthew Francis Digman, U.S. Dairy Forage Research Center, Cell Wall Biology and Utilization Research Unit, 1925 Linden Drive, Madison, WI 53726; phone: 608-890-1320; e-mail: Matthew.digman@ars.usda.gov.

Currently, producers have the option of combining forage swaths with a wheel rake, rotary rake, parallel-bar rake, or belt merger. Each machine has its advantages when considering cost, productivity, final product quality and scalability. This has been the primary focus of the research, as discovered in the literature.

Loss of crop value for both raking and inverting processes has been extensively researched. Savoie et al. (1982) studied both rotary and parallel-bar rakes in 40% wet basis (w.b.) alfalfa. Under these conditions, the loss between the two rakes was not significantly different but was measured to be 2.1% and 2.7% for parallel-bar and rotary rakes, respectively. Under similar conditions, a loss and quality study conducted by Rotz and Abrams (1988) reported dry matter (DM) losses of 0.8% and 3.5% for an inverter and parallel-bar rake, respectively. Focusing on inverters, Savoie and Beauregard (1990b) measured loss from three machine designs. The operating principles of an inverter are nearly identical to that of a merger, but inverters are equipped with special baffling used to invert rather than combine windrows. Savoie and Beauregard found that crop inverted at moisture contents above 40% w.b. resulted in losses of less than 0.5% of DM, a result similar to Rotz and Abrams' study. Most recently, Hoover (1996) studied a parallel-bar rake, wheel rake, inverter, and two types of rotary rakes while concurrently measuring drying rate, DM loss, and rock movement. This work found losses to be 5%, 9%, 3%, and 8% of DM for the parallel-bar rake, wheel rake, inverter, and rotary rake, respectively.

Measurement of loss of crop quality has been less conclusive. Two studies employing inverters reported no change in baled hay quality, as measured by crude protein and detergent fibers (Garthe et al., 1988; Shearer et al., 1992). In a more recent study, however, Buckmaster (1993) found significantly higher DM and quality losses using a novel, "artificial stubble" technique. Average DM losses for a wheel and parallel-bar rake were observed to range from 3.5% to 26.8% of DM and varied depending on crop moisture content and yield. Crude protein decreased with increasing DM loss whereas detergent fiber was less affected, indicating leaves were preferentially lost during raking.

This research, recognizing the worth and relevance of the previous studies, proposes to further our understanding of swath manipulation. Aspects of previous work are challenged by great changes in merger design as well as harvesting practices, limiting their applicability (Dow et al., 2007; Geiser, 2009). In particular, mergers other than inverters have not been studied as they are configured today. Much of the previous work on the performance of rakes and inverters was conducted at much lower moisture than is typically experienced when swaths are merged for harvest with a forage harvester. Thus the primary focus of previous work has been employing raking and inverting to improve drying rate for production of hay whereas many farms in the Midwest and Northeast United States have adopted silage and baleage systems (USDA-NASS, 2009). Additionally, previous studies do not include implications of management practices such as machine adjustment and cutting (stubble) height for decreasing the likelihood of ash incorporation. In the wet-storage system merging losses are expected to be less, but incorporation of ash will be detrimental to the cutting mechanism of the baler or forage harvester. Furthermore, clostridia bacteria incorporated with soil can poison the aforementioned fermentation process, outcompeting lactobacillus and resulting in an unpalatable, potentially poisonous silage (Muck, 1988). If the ash-contaminated crop ferments well or is fed before clostridia fermentation can occur, ash can still be of concern as it occupies volume and therefore displaces valuable energy or nutrients in the diet and reduces animal performance (Hoffman, 2005). Finally, the working rates and subsequent energy use for these processes has not been reported. Fuel use and productivity data will enhance our understanding of the potential to reduce energy of the overall harvest system.

The objectives of this research were to: (1) measure the relative importance of crop moisture at merging and cutting height on incorporation of ash into the consolidated windrow, (2) measure the importance of crop moisture on the impact of leaf loss, and (3) survey ash, fuel use, and productivity of belt mergers in a production setting.

Materials and Methods

Two separate but related experiments were conducted to better understand the working rates, fuel use, leaf loss characteristics, and efficacy of a tine-pickup belt merger to incorporate ash (soil) into merged crop. The first experiment, a full factorial design, explored the influences of cutting height and crop moisture on the incorporation of ash into merged crop. Additionally, leaf loss was studied in response to the ash experiment's moisture factor. The second experiment was conducted as a survey of crop yield, soil contamination, and working rates of the mergers on four farming operations.

The factorial experiment was conducted on 7, 8, and 13 June 2011 in first cutting of a 3-year-old, 4-ha stand of alfalfa (43° 20' 29.058''N, 89° 44' 51.3384''W) at the U.S. Dairy Forage Research Center Farm located in Prairie du Sac, Wisconsin. The soil type where the study was performed was a St. Charles silt loam with 2% slope. Variables consisted of three cutting heights 5.1, 7.6, or 10.2 cm and two levels of crop moisture 40% or 65% w.b. Measured responses included ash content and leaf loss. Each was measured before and after the merging field operation. The experiment was replicated three times over three separate days. Each treatment was conducted on a 4.34- × 152.4-m plot of land and response variables were measured at three locations (repeated measurements). Significance of experimental factors on measured responses and confidence intervals were evaluated using Mathematica (Version 8, Wolfrum Research., Champaign, Ill.). Given the expected field variability, statistical significance was recognized for $P<0.10$.

Crop was cut the afternoon before the field experiment with a self-propelled windrower (2550 Speedrower; CNH America LLC, New Holland, Pa.). The 4.34-m sickle header (2300 Series; CNH America LLC, New Holland, Pa.) was set to lay a swath width of 2 m to maximize drying rate within the constraint of the maximum wheel spacing of the tractor used for the subsequent merging operation as we did not want to run over any part of the swath during merging. Full cutting width of the header was realized by leaving strips of uncut crop between each pass which were subsequently mowed (Shinners et al., 2006). Cutting height was altered by adjusting header-shoe position relative to the sickle. Nominal cutting heights employed in this study were 5.1, 7.6, and 10.2 cm. Stubble height was measured with an acrylic rising plate meter commonly used in pasture yield estimates (Bransby et al., 1977).

The tine-pickup belt merger (MM 300, Kuhn North America, Brodhead, Wis.) utilized in this experiment had a 2.85-m wide pickup with 7-cm tine spacing (Babler and Lust, 2009). Typical of these machines, tine position relative to the ground is held constant by a pickup frame that is mounted to permit multi-axis rotation about the carrier frame. This freedom enables the pickup to be guided by adjustable gauge wheels that precede the pickup. The MM 300 tine position is adjusted relative to the ground by placing concentric metal shims about pin mount between the gauge wheel weldment and pickup frame. Using combinations of the shims provided by the manufacturer, we were able to produce nominal tine relative to ground heights of 2.5, 3.8, and 5.1 cm enabling us to maintain a tine-to-stubble height ratio of 50%. This height ratio ensured that tines sufficiently engaged the stubble while minimizing the potential for tines interacting with the ground. The merger was trailed behind a 2WD, 78 kW row-crop tractor (105U, CNH America, LLC., Racine, Wis.). All merging operations were conducted at 8 km h^{-1}.

Incorporation of ash by the merger was measured by comparing the amount of ash present in the swath after cutting and field wilting to the amount of ash present in the windrow after merging. For brevity, and because wide-swath drying is considered best practice, we refer to swaths as pre-merged crop and windrows as post-merged crop. Swath ash, crop moisture, and yield were determined by taking a 1-m cross-section at three locations spaced at approximately 30.5 m prior to merging. Since only one swath was merged per run, plastic tarps were utilized to prevent the merged crop (windrow) from being placed on the ground. It is common practice to place windrows on top of unmerged swaths thereby preventing the crop from being placed on the ground and thus being contaminated with soil. This practice also increases the effective width of the merger. After merging was completed, windrows were cross-sectioned. All sample material was weighed, chopped through a precision cut stationary chopper, mixed by hand, sub-sampled into three bags weighing approximately 200 g, and oven-dried at 55°C for 48 h. Next, each sample was ground in a Wiley mill (Model 3; Arthur H. Thomas Co., Philadelphia, Pa.) to pass through a 2-mm screen. Dry matter (DM) was determined as loss on drying in a forced air oven; the temperature and drying time were 103°C and 24 h per ASABE S358.2 (*ASABE Standards,* 2008). Ash content was determined sequentially after DM as residue remaining after combustion at 500°C for 4 h. Harvested crop yield and moisture were measured utilizing the previously mentioned swath cross sections taken for ash measurement. The area was estimated as the product of the cutting platform width (4.34 m) and swath cross section (1 m).

Leaf loss was measured beneath the swath cross section before merging and at a nearby location after merging. Leaves were collected with a wet-dry vacuum coupled with a cyclone separator (Dust Deputy, Oneida Air Systems, Inc., Syracuse, N.Y.) from a 0.5- × 0.5-m square in a method similar to Rotz and Sprott (1984). The resulting mixture of leaves, decaying crop residue, and soil were then dried in a forced-air drying oven at 103°C for 24 h. Next, soil and crop residue were separated from the leaves by first sieving through a 0.6-mm opening (No. 30-mesh) sieve to remove fine soil particles and then by differential terminal velocity utilizing a South Dakota Seed Blower (Seedburo Equipment Company, Des Plaines, Ill.). Clean leaf fractions were then weighed and divided by sampling area (0.25 m^2) to obtain leaves lost per ha. These values were also compared to yield to determine leaves lost as a percentage of total-harvestable yield.

The water content of the soil was measured from four 2.54 cm i.d. × 1.59 cm long soil cores taken beneath the cross-sectioned swath. Cores at each location were then combined into one soil tin. Water content was determined as the quotient of mass lost (water) after forced-air oven drying, 55°C for 48 h and the material remaining (dry soil) expressed on a dry basis (Gelderman and Mollarino, 1998).

The field survey methods depended on many of the same field and laboratory techniques as the factorial experiment. The field survey did, however, add monitoring of fuel use, tractor speed and weight, and harvesting practices. A field campaign began by first taking detailed notes on the tractor's make, model, optional ballast status along with the make and model information of the merger. At this time a controller area network (CAN) data logger (GL1000, Vector Informatik GmbH; Stuttgart, Germany) equipped with a GPS receiver (CANgps V1.18, G.i.N. mbH; Griesheim, Germany) was installed in the tractor powering the merger. The logger was programmed to log (filter) GPS messages including position, altitude, heading and speed, and tractor messages including engine speed and fuel rate.

Next, three sections of pre-merged swath, approximately 30.5 m apart, were assayed for ash inclusion using the methodology previously described. Similarly, stubble height, soil water content, and yield were also measured. As the merger passed each sample area the times were noted so that CAN data (speed, engine speed, fuel rate) could be correlated with each field observation. Four field locations were observed at each farm yielding a total of 12 observations. CAN data were formatted, sorted, and analyzed with a custom Mathematica script. Merging speed, engine speed, and fuel rate were averaged over 60 s centered about the time of the field observation. Headland time was also gleaned from the CAN data by first overlaying the field path on an aerial image and then manually calculating the time lapsed for the headland maneuver. Map projection and data exploration were automated using the Spatial Management System™ (SMS

Basic, Ag Leader Technology, Ames, Iowa). Confidence intervals were evaluated using Mathematica as previously described.

RESULTS AND DISCUSSION

Field efficiency, leaf loss, and the efficacy of a tine-pickup belt merger to incorporate ash (soil) into windrows were investigated by on-farm observation and through a controlled experiment. First, we examine the results of the controlled experiment. As previously described, this was a full factorial design with three replications, which included cutting height and moisture as treatment variables. Standing crop yield and ash were measured in six locations at a 10.2 cm cut height to be 4.05 ± 0.67 Mg ha^{-1} and 72.3 ± 3.0 g (kg DM)$^{-1}$, respectively.

Table 1 reveals the impact of cutting height on stubble height irrespective of the moisture factor. As cutting height increased, stubble height increased whereas yield, swath and windrow (post-merging) ash content numerically decreased. A statistical difference in windrow ash content was realized by adjusting the mower and merger from the lowest to the highest cutting height. The numerical trend in the swath data reveal that part of the difference could be attributed to compositional variation in the standing crop or from the mowing field operation or both. However, the small differences in ash achievable were at the cost of significant differences in yield. Yield loss was well described by a linear model (R^2 = 0.98) with a slope of 0.16 Mg ha^{-1} cm^{-1} which is lower than the 0.31 Mg ha^{-1} cm^{-1} proposed by Wiersma et al. (2007). In summary, over the range of cut heights observed, we would conclude that it is not practical to manage ash content of the harvested crop with cutting height given the magnitude of yield loss relative to the changes achievable in windrow ash content.

The second factor considered to have an impact on windrow (post-merging) ash content was crop moisture (table 2). The high and low treatment moistures averaged to 61.2% and 39.8% w.b., respectively; each about five moisture points below our target. Swath moisture content did not significantly contribute to the amount of ash observed but ash values were numerically higher for the low moisture treatment. However, post-merging ash levels were observed to be significantly higher at the lower moisture content. This observation may be explained as follows: at the low moisture the soil beneath and surrounding the swath is drier and more friable thereby increasing the possibility of windrow contamination. As with the cutting height factor, the ash difference observed for the moisture factor is of little practical significance.

Table 1. Cutting height factor treatment means for stubble height, yield, pre- (swath) and post- (windrow) merging ash responses.

Factor	Measured Response[a],[b]			
Cutting Height (cm)	Stubble Height (cm)	Yield (Mg ha^{-1})	Ash Content Swath g (kg DM)$^{-1}$	Ash Content Windrow g (kg DM)$^{-1}$
5.1	6.9$_a$	4.66$_a$	80.5$_a$	81.3$_a$
7.6	8.7$_b$	4.42$_a$	79.8$_a$	80.3$_{ab}$
10.2	10.8$_c$	3.87$_b$	79.2$_a$	80.0$_b$
LSD		0.3	2.2	1.1

[a] Within a column, values followed by different letters are significantly different at α = 0.10.
[b] Responses averaged across all levels of the moisture factor.

Table 2. Crop moisture factor treatment means for pre- (swath) and post- (windrow) merging ash and loss responses.

Factor	Measured Response[a]			
Crop Moisture (% w.b.)	Soil Moisture (% d.b.)	Ash Content Swath g (kg DM)$^{-1}$	Ash Content Windrow g (kg DM)$^{-1}$	Leaf Loss (%)
61.2	26.9	79.1$_a$	79.9$_a$	1.2$_a$
39.8	23.8	80.8$_a$	81.3$_b$	2.2$_b$
LSD		2.2	1.1	0.5

[a] Within a column, values followed by different letters are significantly different at α = 0.10.
[b] Responses averaged across all levels of the cutting height factor.

Table 2 also summarizes our leaf loss observations. Leaf loss was observed to be significantly higher at the lower crop moisture content. At the low moisture level, leaf losses were observed to be at similar levels as those observed at similar moisture conditions in rakes as reported by Savoie et al. (1982), but lower than those reported by Hoover (1996). Conversely, at the higher moisture level our loss values were higher than reported elsewhere in the literature. Both Rotz and Abrams (1988) and Savoie and Beauregard (1990a) reported leaf (shatter) losses less than 1% for inverters. However, Hoover (1996) reported leaf (shatter) losses at the 3% level. Based on our work and comparable data in the literature, it is reasonable to conclude that common design elements between inverters and mergers result in similar crop handling and subsequent loss characteristics.

In the second part of this work we explored ash content, fuel use, and productivity of crop merging through on-farm observation (table 3). Five machines were observed in second cutting alfalfa on four farming operations in central Wisconsin: two custom harvesters and two owner-operators. Merger and tractor weight were determined by adjusting the manufacturer's specification for optional ballast observed in the field. These data are reported as context for subsequent productivity and fuel rate data. Manufacturers (Oxbo International Corp., Clear Lake, Wis.; H&S Manufacturing Company, Inc., Marshfield, Wis.; Kuhn S.A., Saverne, France) recommend tractor sizes between 101 and 112 kW. Tractors observed in the study varied by operation but either met or exceeded manufacturer's specification. The two front-wheel assist tractors observed were being utilized for merging but were specified for seasonal towing of liquid manure tankers. Harvester size varied significantly by operation irrespective of merger size.

The utilization of the mergers was observed as follows. Each operation observed employed two mergers just ahead of the harvester. Specifically, mergers were no more than 1 h ahead of the harvester and in some cases the time window was nearly too short for our field measurements. Although all mergers observed employed a continuous pickup design and therefore could merge independent of swath placement, operators followed the swaths except where irregular field shape dictated overlap. Operations B, C, and D increased the total merged area and subsequent theoretical field capacity by placing merged windrows on top of a central

Table 3. Harvesting system - mower, tractor power unit, merger and harvester - configurations observed on four alfalfa silage making operations in central Wisconsin.

	Mower		Merger Tractor			Merger		Harvester
Operation	Type[a]	Width (m)	Type	Engine Size (kW)	Weight (Mg)	Width (m)	Weight (Mg)	Engine Size (kW)
A	Mounted	8.8	FWA	128	9.92	10.7	6.07	597
B-1	SPWR	4.9	2WD	114	7.69	10.7	7.39	358
B-2	SPWR	4.9	2WD	106	7.69	10.3	6.07	358
C	Mounted	8.8	2WD	140	8.45	10.7	7.39	597
D	Mounted	8.8	FWA	181	10.26	10.7	6.07	650

[a] SPWR - self-propelled windrower; FWA - front wheel assist, 2WD - two wheel drive.

unmerged swath (table 4). Regardless of practice, the width merged varied by no more than 3 m regardless of mower width or merging practice. Field speeds ranged from 11.4 to 13.5 km h^{-1} which are higher than previously reported for side-delivery rakes or inverters (Rotz et al., 1983; Shearer et al., 1992). Theoretical field capacity, accounting for a 5% overlap loss from the mowing operation, was more sensitive to merging pattern and speed than mower cut width (Shinners et al., 2011).

Observed fuel rates, assuming an 80% field efficiency, ranged from 1.7 to 1.9 L ha^{-1} but were not measured for operations C and D because the fuel rate CAN data was not available. Each operation merged with engine speed below rated PTO speed. Engine speeds were 79%, 94%, 93%, and 80% of rated PTO speeds for operations A, B-1, B-2, and C, respectively. Engine speed and subsequent fuel rate could be further reduced if the mergers could alter pickup and belt speed independent of tractor PTO speed. Currently few merger designs incorporate this feature. Therefore, limiting engine speed reduces PTO speed, which can limit forward speed as the pickup does not sufficiently keep pace with ground speed. If this feature could be incorporated in more merger designs, operators would have a greater opportunity to manage fuel consumption.

Fuel rates were also compared to a calculated rate determined by the merger manufacturer's power specification, engine speed observed, and tractor Nebraska test data (*ASABE Standards,* 2011). In cost modeling it is common practice to utilize implement manufacturer's tractor size requirements to estimate power required for a field operation and subsequent energy use (Rotz and Muhtar, 1992). This methodology estimated fuel consumptions of 30.1, 33.9, and 30.4 L h^{-1} for operations A, B-1, and B-2, respectively. However, these estimates were quite a bit higher than observed. One explanation is that the tractor size for the wide-area mergers is dictated by the vertical draft (hitch weight) for semi-mounted design rather than draft or rotary power requirements. Vertical draft requirements ranged from 1,557 to 3,626 daN or from 35% to 50% total machine weight. Based on these observations, use of typical machinery management model assumptions will lead to conservative fuel estimates in continuous pickup belt mergers.

Merging moistures averaged 54.5% w.b. and varied little between operations (table 5). This value is slightly higher than the 51% w.b. but within the range of 65% to 47.9% w.b reported for second cutting data in the 2011 Wisconsin Alfalfa Yield and Persistence Program (WAYP) (Rankin, 2011). The soil type and moisture varied little between operations. Similarly, stubble height was very consistent between operations and was observed to be close to the medium height (7.62 cm) utilized in our factorial study. Crop yield was also observed to be consistent between operations B, C, and D but was lower for A. Operation A was the first operation observed as it utilized a 30-day interval, a harvest strategy favoring quality (*viz.* high protein, low NDF) over yield. Yields observed in this study were higher than observed in the 2011 WAYP where second cutting yields range from 1.2 to 2.9 Mg ha^{-1} but were similar to the 3.34 Mg ha^{-1} average observed in 2010 (Rankin, 2011).

Ash levels varied by operation, but there were no differences between swaths (un-merged) and windrows (merged) within each operation. In fact, in three of the four operations, ash content was numerically lower in the windrow than the swath. Ash levels reported in this survey were within the range of alfalfa haylage data reported by Dairyland Laboratory, a regional forage testing laboratory, of 86.2 to 148.1 g(kg $DM)^{-1}$ but lower than the mean value of 117.1 g(kg $DM)^{-1}$ (DLFS, 2011). These survey data

Table 4. Merging practices and resulting machine parameters observed four alfalfa silage making operations in central Wisconsin.

	Tractor[a]			Merger			
Operation	Speed km h^{-1}	Engine Speed (rpm)	Fuel Rate (L h^{-1})	Merging Pattern[b] (i-j-k)	Width Merged (m)	Headland Time[a] (s)	Theoretical Field Capacity[a],[c] (ha h^{-1})
A[d]	13.3 ± 0.5	1738 ± 14	20.4 ± 0.8	4-0-4	22.4	8.2 ± 0.9	14.7
B-1	11.4 ± 0.4	1841 ± 9	18.2 ± 0.8	2-1-2	23.3	9.5 ± 0.7	13.2
B-2	12.1 ± 0.9	1827 ± 22	21.3 ± 0.8	2-1-2	23.3	7.8 ± 0.5	14.0
C[d]	13.5 ± 0.2	1763 ± 25	-	4-1-4	25.2	9.3 ± 0.9	16.9
D[d]	-	-	-	4-1-4	25.2	-	-

[a] Mean ±90% confidence interval.
[b] i-j-k, i first pass swaths merged onto j swaths and k swaths second pass.
[c] Theoretical field capacity is calculated from the cut width contained within the swaths picked up by the merger (*viz.* i or k) as well as half of the cut width those swaths are placed on (j).
[d] Because a mounted, modular mower configuration was utilized, each swath (j) represents a 2.8-m cut width assuming a 5% mower pass-to-pass overlap and one-third of total mower width.

Table 5. Ash levels and field conditions observed on four alfalfa silage making operations in central Wisconsin.

	Soil		Crop[a]			Ash Content[a]	
Operation	Dominant Rating	Moisture[a] (% d.b.)	Moisture (% w.b.)	Stubble Height (cm)	Yield (Mg ha^{-1})	Swath g (kg DM)$^{-1}$	Windrow g (kg DM)$^{-1}$
A	Navan silt loam	15 ± 2	55 ± 2	7.6 ± 0.6	2.9 ± 0.3	106 ± 4	104 ± 3
B	McHenry silt loam	18 ± 2	54 ± 2	7.5 ± 0.4	3.4 ± 0.4	81 ± 3	81 ± 3
C	Plano silt loam	18 ± 2	54 ± 2	7.3 ± 0.3	3.4 ± 0.3	84 ± 2	83 ± 3
D	McHenry silt loam	16 ± 2	55 ± 2	7.3 ± 0.3	3.5 ± 0.2	99 ± 4	100 ± 4

[a] Mean ± 90% confidence interval.

agree with the experimental data on the impact of belt mergers on ash incorporation.

SUMMARY

Current cutting practices minimize ash incorporation while maximizing harvested crop yield. As revealed in our field survey, cutting height is being managed at 7.5 cm, which is similar to the medium level studied in our factorial experiment. The medium level (7.6 cm) lead to statistically lower ash than the low (5.1 cm) but was not different than the high cutting height (10.2 cm). Furthermore, at high cutting heights (>7.6 cm) the value of yield loss will likely outweigh the value associated with lower ash in the harvested crop. Finally, it was observed that even at the low cutting height the merging process did not lead to appreciable contamination of the windrow with ash.

Based on our observations, theoretical field capacity of mergers is sensitive to merging pattern, speed and, to a lesser extent, mower cut width. Although the continuous pickup design enables merging independent of swath placement, most operators reserve this for irregular areas of the field. The large pickups did enable the operators to negate the effect of mower cut width as it relates to merger theoretical field capacity.

Fuel rates were kept low for the merging operation by reducing tractor engine speed below PTO rated speed. The combination of this management practice and the need for a tractor that can handle significant vertical draft (tongue weight) lead commonly employed model assumptions to predict higher fuel rates than observed in the field. Engine speed and subsequent fuel rate could be further reduced if mergers were designed with the capability of altering pickup and belt speed independent of tractor PTO speed.

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